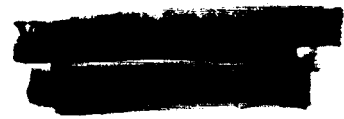Preprint of Paper

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IONIZATION CROSS SECTIONS FOR NEUTRAL HELIUM ATOMS

ON HELIUM, NEON, AND NITROGEN*

Nyle G. Utterback

University of Denver
Denver 10, Colorado

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Nyle G. Utterback
University of Denver
Denver 10, Colorado

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Abstract: The ionization cross sections for He atoms on impact with He and Ne atoms and N_2 molecules have been measured over the laboratory energy range from 40 to 1000 eV. The incident atomic beam was produced by the technique of ionization by electron impact, electrostatic acceleration, and neutralization by charge transfer. The measurements were carried out in a low-pressure parallel plate ionization chamber. Particular attention was paid to the problem of secondary electrons. The ionization cross sections obtained for the He-He and He-Ne interactions were smaller than 5×10^{-17} cm^2 over the energy range studied, and were thus one-to-two orders of magnitude smaller than the N_2-N_2, N_2-O_2, and O_2-O_2 cross sections studied earlier. The He-N_2 cross section, on the other hand, was found to be of the same order of magnitude as the N_2-N_2 cross section.

1. Introduction

Three previous papers[1,2,3] have described the development of fast N_2 and O_2 molecular beams and their application to the measurement of the ionization cross sections for N_2-N_2, N_2-O_2, O_2-N_2 and O_2-O_2 (neutrals on neutrals). The present paper reports an extension of this work to the measurement of the He-He, and He-Ne, and He-N_2 ionization cross sections.

[1] N. G. Utterback and G. H. Miller, Rev. Sci. Instr. 32, 1101(1961).

[2] N. G. Utterback and G. H. Miller, Phys. Rev. 124, 1477(1961).

[3] N. G. Utterback, Phys. Rev. 129, 219(1963).

The technique was the same as used previously,[2,3] and consisted of three basic parts. First, an atomic helium beam was produced having the desired energy. Second, a He, Ne, or N_2 gas thin target was provided for this beam between the plates of a parallel plate ionization chamber. Finally, the electrons (or possibly negative ions) produced in ionizing collisions were swept by the electrostatic field between the plates to the collector plate and this current was measured. It was possible to determine the ionization cross section through knowledge of the incident beam intensity, target particle density, guarded collector length, and the collector current. The major experimental difficulty involved verifying that the collector current corresponded to ionization electrons rather than secondary electrons produced at chamber surfaces.

2. He-He Measurement

The apparatus used for the He-He ionization cross section measurement was the same as used previously for N_2-N_2, and the technique was identical. The He-He measurement was considerably more difficult due to background problems caused by the much smaller inherent reaction cross section.

The helium ions were produced by bombardment of helium with 45 eV electrons. The charge transfer cross section for He^+ in He was measured as a consistency check as in reference 3. The results (15 x 10^{-16} cm^2 for 100 eV ions) were consistent with other investigations.[4,5]

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[4] H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. A238, 334(1957).

[5] W. H. Cramer and J. H. Simons, J. Chem. Phys. 26, 1272(1957).

The method for obtaining the helium atom beam intensity was checked as previously[1] by measuring the secondary electron emission coefficient for ions (γ^+) and neutrals (γ^o) from a gold surface. It was found that γ^+ and γ^o were equal within 20% above an energy of 400 eV. Below that energy, γ^o decreased smoothly toward zero while γ^+ saturated toward a value of 0.2 as the energy was decreased. At 1000 eV, γ^+ and γ^o were about 1.4. Saturation of the cross section values with target pressure and ion chamber electrode potentials was achieved for He-He. However it was necessary to go to higher target pressures (0.8 micron Hg) and grid-to-collector potentials (1200 volts) than previously,[2,3] before saturation was achieved.

Figure 1 shows the results obtained for the He-He ionization cross section. The previously obtained curve[2] for N_2-N_2 is plotted for comparison. The abscissa is the center of mass energy minus the ionization potential for the species involved, and thus corresponds to excess energy over the threshold. For the N_2-N_2 curve, E_i equals 15.6, and for He-He, E_i equals 24.5.

3.   He-Ne Measurement

The He-Ne measurement was made in the same manner as the He-He, except that Ne was used as the target gas. In this case some Ne was present in the neutralization chamber due to target gas entering through the cup exit aperture. The He^+ in Ne charge transfer cross section was measured and was found to be negligible. This is consistent with other work.[6] The neutralization was thus through the reaction He^+ in He.

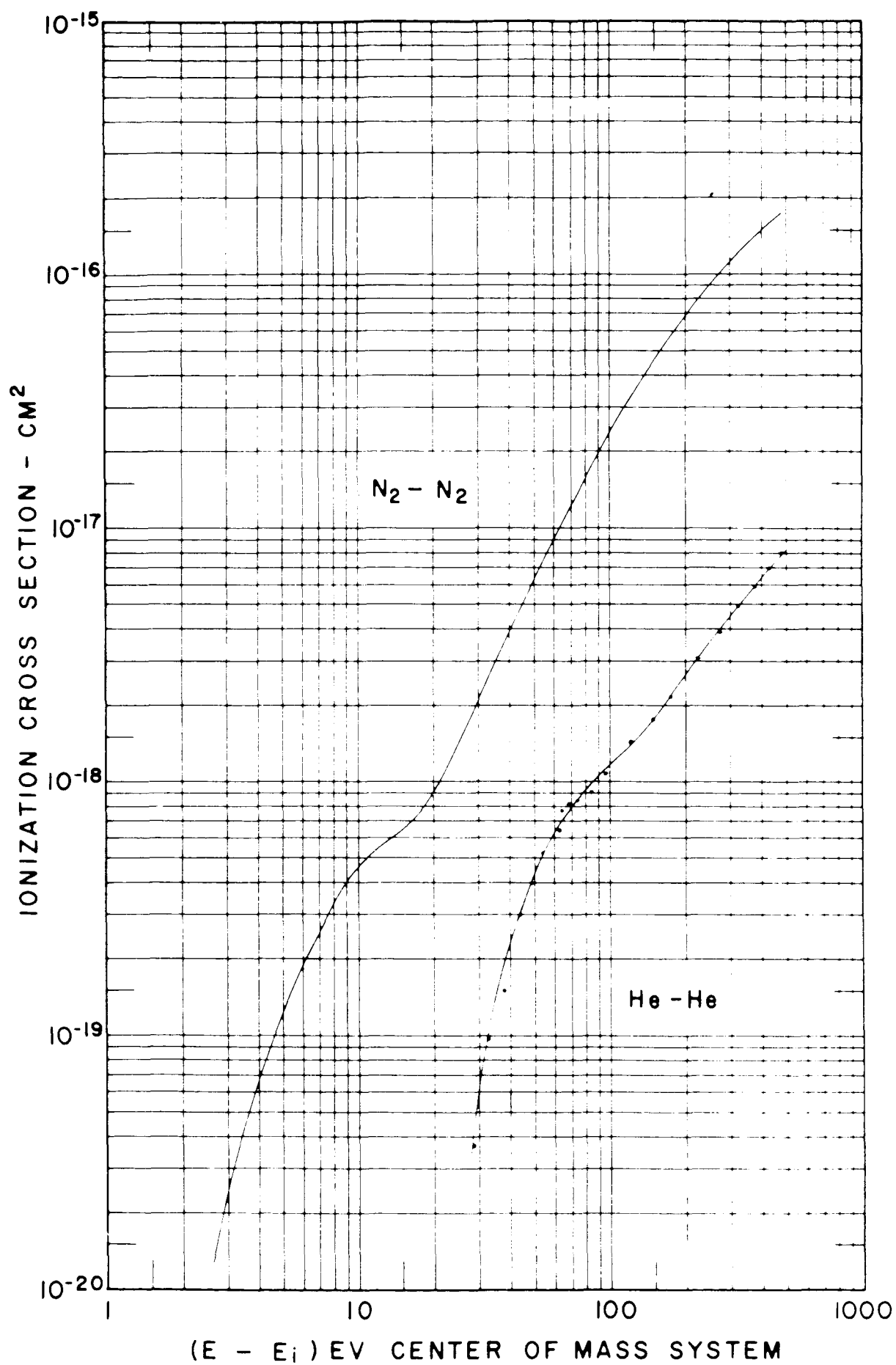[6] W. H. Cramer, J. Chem. Phys. __28__, 688(1958).

Figure 1. He-He Ionization Cross Section.

The He impurity in the Ne target gas arising from flow from the
neutralization chamber had negligible effect on the measured He-Ne ion-
ization cross section. The He concentration was low, and the He-He
ionization cross section was always smaller than the He-Ne cross section
for the same beam energy.

Figure 2 shows the results obtained for the He-Ne ionization cross
section, again compared to N_2-N_2. In the case for He-Ne, E_i for the
abscissa value was taken to be 21.5 eV.

4. He-N_2 Measurement

The He-N_2 measurement was made in the same manner as the He-He, with
N_2 as the target gas. In this case, the N_2 present in the neutralization
chamber did account for some neutralization. The He^+ in N_2 charge trans-
fer cross section was measured to be almost as great (13×10^{-16} cm^2 at
100 eV) as the He^+ in He cross section. This is consistent with other
work.[7] It appeared however that the neutralization by the N_2 led to no
inconsistencies in the data.

The He-N_2 ionization cross section was so large that the He present
in the target gas (arising from the neutralization chamber) could be
ignored.

Figure 3 shows the results obtained for the He-N_2 ionization cross
section, compared to N_2-N_2. The value E_i for the abscissa energy was
15.6 for both curves on Figure 3.
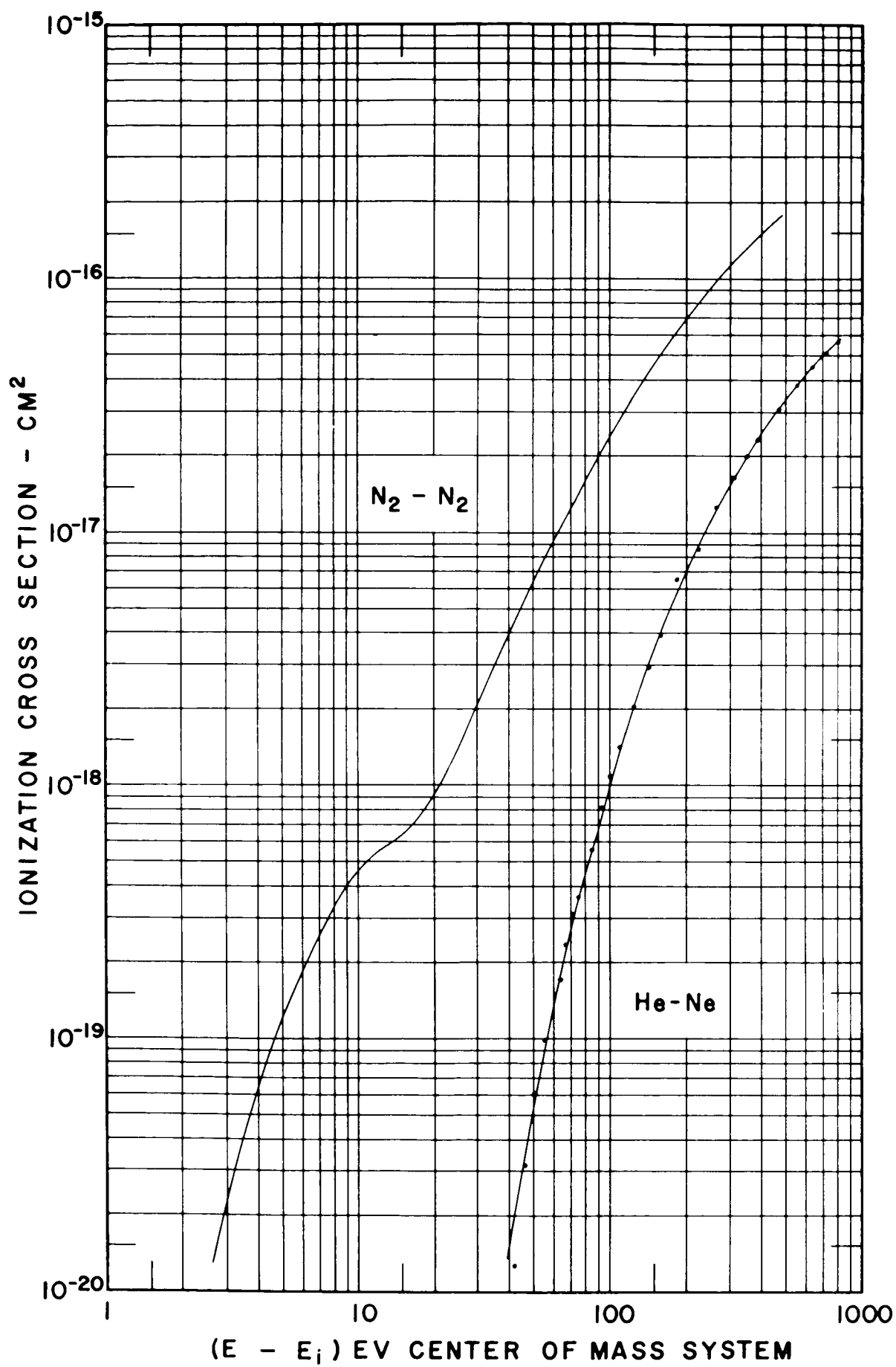
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[7] R. F. Stebbings, Private Communication.
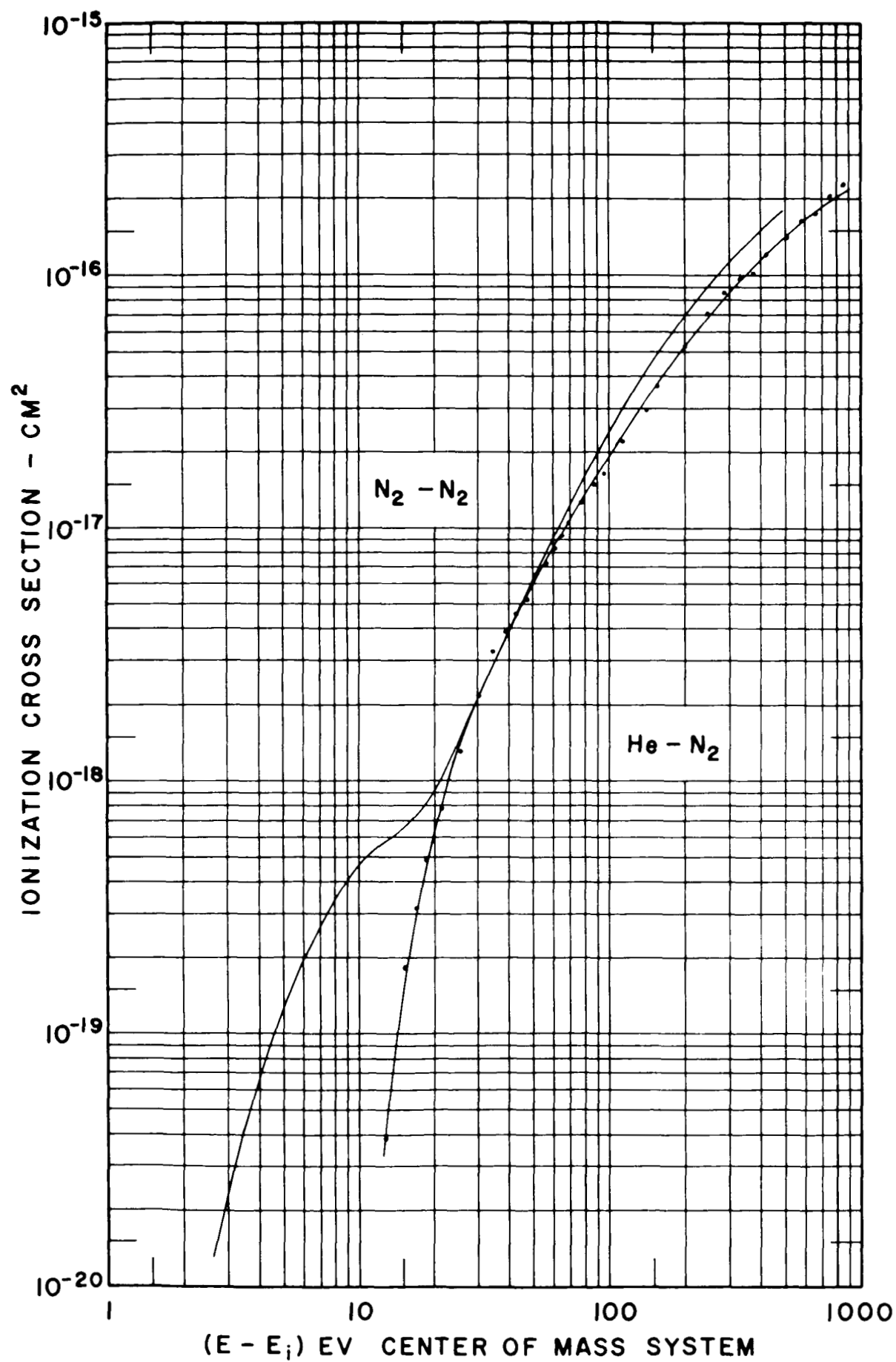
Figure 2. He-Ne Ionization Cross Section.

Figure 3. He-N$_2$ Ionization Cross Section.

5. Discussion

The accuracy of the data presented in Figures 1, 2 and 3 should be about the same as in the previous papers,[2,3] namely, $\pm 25\%$. Not all of the consistency checks which are desirable have been completed at the time of writing of this paper, but there is nothing so far to indicate any greater uncertainty. It is expected that a more detailed paper will be published in the open literature at a later date.

The most striking feature of the ionization cross sections is the large cross section occurring when a molecular species is involved. It may be noted that the cross sections for N_2-N_2 and He-N_2 are quite similar except for the structure in N_2-N_2. On the other hand, the He-He and He-Ne cross sections are an order of magnitude smaller.

It appears that structure is present in He-He curve. As in the case of N_2-N_2, there is no easy explanation for such structure. The He-Ne and He-N_2 curves by contrast are quite smooth.

Berry[8] has found structure in the ionization electron energy distribution for the He-He ionizing interaction which he attributes to formation of intermediate states. It is very likely that the structure found here is related to the structure found by Berry.

Acknowledgment

The author wishes to thank Mr. Howard Hayden for his assistance in this work.

[8] H. W. Berry, Phys. Rev. 121, 1714(1961).